Application of Distributed Static Series Compensator for Improvement of Power System Stability

Praful P. Kumbhare, Akhilesh A. Nimje and Pankaj R. Sawarkar

Abstract This paper is based on the basic performance analysis of Distributed Static Series Compensator (DSSC) required for the improvement of power system stability. The DSSC has small size and weight with cylindrical structure that is put on the line conductor without grounding. It has the capability of changing the impedance and altering the power flow through the lines. The fundamental behavior of DSSC and Static Synchronous Series Compensator (SSSC) is similar. However, a DSSC costs less and higher reliability. In this paper, single machine infinite bus system (SMIB) has been simulated in PSCAD for various operating conditions of power system such as steady state and during fault conditions.

Keywords D-FACTS · DSSC · FACTS · PSCAD · SMIB · Stability

1 Introduction

Modern power system has an interconnected grid network that covers generation, transmission, and distribution. The generating stations are located far away from the consumers with a transmission network that requires high degree of reliability to facilitate the uninterrupted power supply at load centers. Expansion of the transmission system requires huge investment and hence the power system engineers attempt to utilize the full capacity of the existing transmission lines. The term Flexible Alternating Current Transmission System (FACTS), in simple words, means applying flexibility to electric power system. It refers to the ability to accommodate changes in the electric transmission system or operating conditions

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while maintaining sufficient steady state and transient margins. The power system stability plays a vital role in power system as the load keeps on changing. A step change in the input voltage may cause small signal disturbance while the three phase faults lead to large disturbance in power system. Thus, stability is defined as the ability of power system to regain synchronism after being subjected to some form of disturbance within least possible time [1]. FACTS technology is the best option for today's power systems scenario for the improvement of power flow in transmission lines, maintaining voltage profile and improving system capability by damping the power oscillations. FACTS technology has a family of controllers with various configurations such as series, shunt, series–series, and series–shunt.

However, widespread use of this technology is restricted due to increase in cost and poor reliability. The device requirements of more component and complexity increase the cost of installation while the single-point failure may shut down the whole system. These limitations are overcome by of the use of Distributed FACTS (D-FACTS) devices [2].

2 Distributed FACTS

Distributed Flexible A.C Transmission system is an advanced version of FACTS system which not only improves the power transmission capability but also improves the reliability and security within the permissible cost. It reduces the power flow through overloaded lines, minimizing losses and cost. The weak and low stability networks required number of modules of D-FACTS devices. The various D-FACTS controllers are distributed series impedance, distributed series reactor, and distributed static series compensator.

2.1 Distributed Static Series Compensator

A DSSC is a voltage-sourced converter and has the objective to provide compensation to the line by improving the voltage across the impedance of respective transmission line. This helps to increase the power flow and current. It consists of a single-turn transformer (STT), single-phase inverter, and a controller. STT has higher turns ratio as a result of which the current through the inverter is reduced and IGBTs can easily used here for reducing the cost [3]. The primary winding of STT is connected with the inverter and the secondary is the transmission line. When DSSC is clamped on the transmission line, a core magnetic circuit is formed around the primary and secondary winding of transformer. Each module consists of a control circuit with communication system in order to coordinate the operation. When DSSC starts, the inverter voltage and line current are in phase, only the real power is extracted from the transmission line to charge the DC bus capacitor. It injects the reactive impedance or quadrature voltage in series with the transmission line. Thus, there is increase or decrease in power along the line [4]. The feasibility of DSSC has been tested in PSCAD and the power oscillations obtained during fault have been damped satisfactorily.

2.2 Role of DSSC for Power Flow Improvement

Figure 1 shows two parallel lines (20 and 30 miles) having voltage level 132 kV. The impedance is (0.17 + *j*0.8) ohm/miles for each line Tables 1 and 2.

From the above calculation, it has been concluded that about 20% power flow is improved by providing compensation (or connecting DSSC) to the transmission line [5].

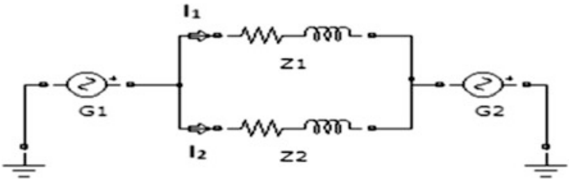

Fig. 1 Two-generator parallel line circuit

Table 1 Given data

(a) Test data	
Without DSSC	With DSSC (A variation of ± 20% in line impedance)
G1 = 132° kV, $\delta 1 = 7.95°$	G1 = 132.0° kV, $\delta 2 = 9.48°$
G2 = 1327.95° kV	G2 = 1329.48° kV
Z1 = (3.4 + *j*16) Ω = 16.35778°	Z1 = [(3.4 + *j*16) + *j*3.2] Ω = 19.580°
Z2 = (5.1 + *j*24) Ω = 24.53578°	Z2 = [(5.1 + *j*24) − *j*4.8] Ω = $198{,}675.124^{\circ}$

Table 2 Improvement of power and current by injecting impedance

(b) Calculation	
(i) Without DSSC	(ii) With DSSC
$P_1 = \frac{V_1V_2}{Z_1}\sin\delta = \frac{132^2}{16.35}\sin(7.95) = 147\,\text{MW}$	$P_1 = \frac{V_1V_2}{Z_1}\sin\delta = \frac{132^2}{19.5}\sin(9.48) = 147\,\text{MW}$
$I_1 = \frac{2v\sin\left(\frac{\delta}{2}\right)_1}{Z_1} = \frac{2(132)\sin\left(\frac{7.95}{2}\right)}{16.35} = 644\,A$	$I_1 = \frac{2v\sin\left(\frac{\delta}{2}\right)_2}{Z_1} = \frac{2(132)\sin\left(\frac{9.48}{2}\right)}{19.5} = 644\,A$
$P_2 = \frac{V_1V_2}{Z_2}\sin\delta = \frac{132^2}{24.54}\sin(7.95) = 98\,\text{MW}$	$P_2 = \frac{V_1V_2}{Z_2}\sin\delta = \frac{132^2}{19.86}\sin(9.48) = 145\,\text{MW}$
$I_2 = \frac{2v\sin\left(\frac{\delta}{2}\right)_1}{Z_2} = \frac{2(132)\sin\left(\frac{7.95}{2}\right)}{24.54} = 430\,A$	$I_2 = \frac{2v\sin\left(\frac{\delta}{2}\right)_2}{Z_2} = \frac{2(132)\sin\left(\frac{9.48}{2}\right)}{19.86} = 632\,A$

iii) Power flow between two buses

	V (kV)	XI (Ohm)	Ohm	Ohm	Degree	I (amp)	*P (MW)*
Line1 initial	132	16	0	16	7.95	644	*147*
Line2 initial	132	24	0	24	7.95	430	*98*
Line1 + DSSC	132	16	+3.2	19.2	9.48	644	*147*
Line2 + DSSC	132	24	−4.8	19.2	9.48	632	*145*

3 System and Controller Details

3.1 System Representation

Figure 2 shows a generator connected to infinite bus. Each DSSC injects maximum 2 V into the line through single-turn transformer of 1:75 ratios.

Figure 3 shows the simulated DSSC module. Each transmission line is connected with three DSSC modules which increase the active power flowing through a transmission line by 0.6 MW [6, 7]. Again, a three-phase line to ground fault is activated at generator side for measuring the impact of DSSC for damping the oscillation produced due to fault.

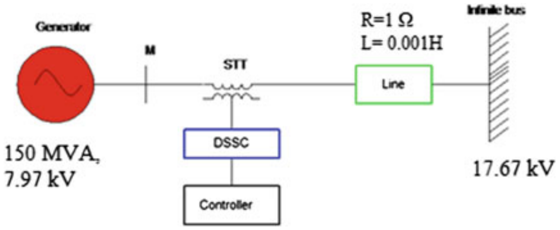

Fig. 2 SMIB with DSSC

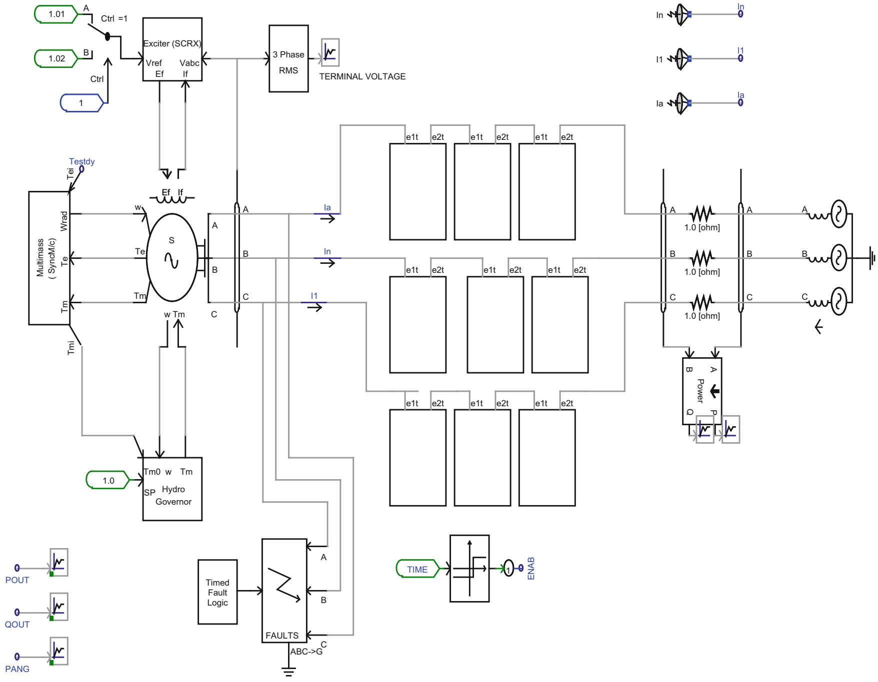

Fig. 3 System model in PSCAD with DSSC

3.2 Control Model

The primary function of DSSC is to control the flow of power in transmission line. This requirement can be achieved by providing control to the system directly or indirectly [8, 9, 10]. There are few limitations of direct control such as complexity in circuit, increased losses, and increased harmonic content. Hence, it is recommended to use indirect controller [11, 12]. The error signal is generated by comparing dc voltage with reference voltage and is given to PI controller and it generates the necessary phase displacement. The phase-locked loop (PLL) gives the basic synchronization angle θ which is the phase angle of system line current. The obtained angle from PI and PLL is given to PWM inverter so control firing of IGBTs is obtained. A filter is provided in the control circuit for reducing the ripples from the system (Figs. 4 and 5).

Controller shown in Fig. 5 is designed in PSCAD. A signal g1p, g1n, g2p, and g2n generates from controller and are used to generate the firing signals for converter. With the variation in firing angle, the injected voltage is controlled.

4 Simulation and Result

The PSCAD model of single generator infinite bus system shown in Fig. 3 is simulated in the steady state with and without DSSC. The transmitted power flow in line is increased by connecting a number of DSSCs.

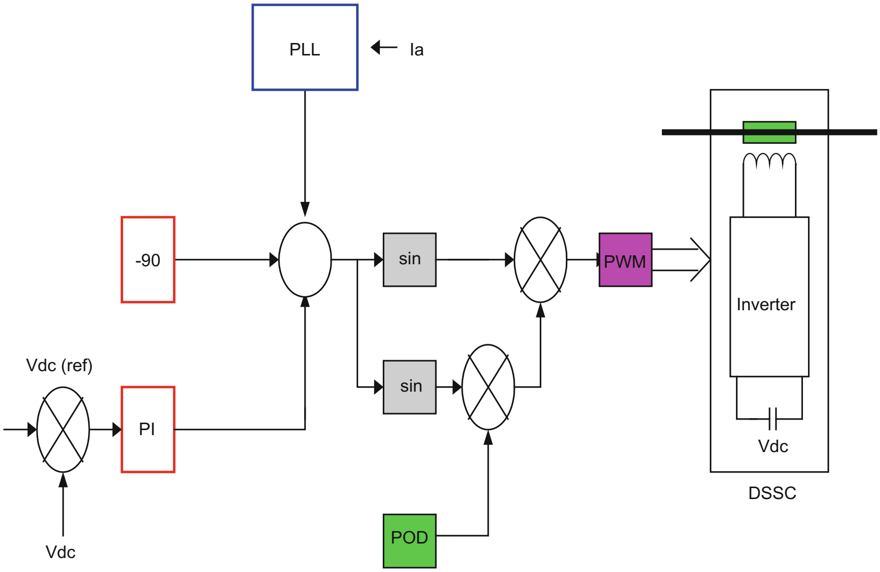

Fig. 4 Control model of DSSC

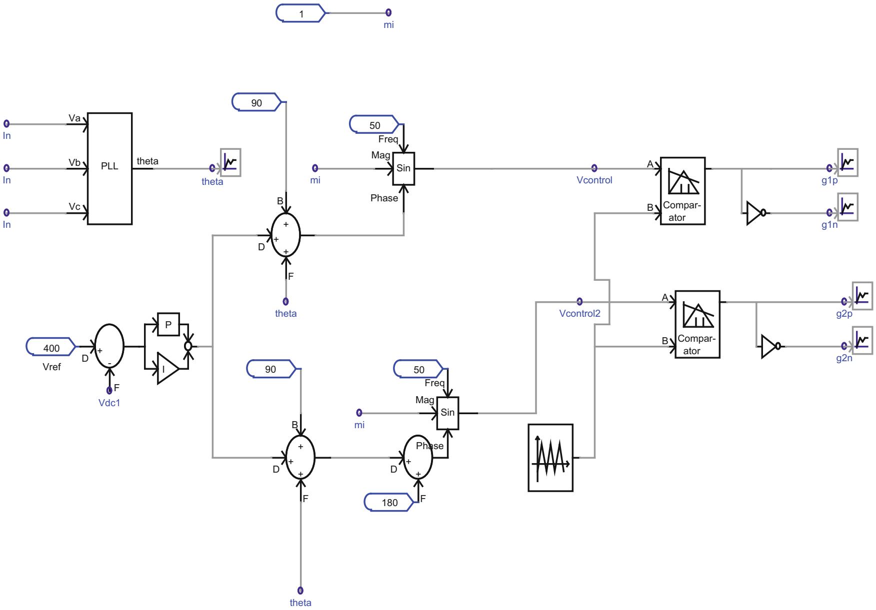

Fig. 5 Control scheme of DSSC in PSCAD

4.1 Steady-State Operating Condition

The system shown in Fig. 2 is a single-generator infinite bus designed in PSCAD software which is simulated considering the same parameter of Sect. 3. Active power measures 85 MW at steady state (without fault) when DSSC is out of system. After connecting a single DSSC in each line of a system, the power increased up to 0.2 MW. In a complete system, 9 number of DSSC are connected, that generates 1.8 MW of power (Fig. 6).

4.2 Dynamic Condition (Considering Power Angle of Generator)

To understand the dynamic performance of DSSC, a symmetrical fault is created at 1.0–1.05 s on the generator side. Figure 7 shows the power oscillation with and without DSSC.

Without DSSC	With DSSC
Power angle escalates up to 124.07° at 1.010 s, when fault is done on 1.00 s. After fault clearance, it is settled at 33°	Power angle escalates to 108.07° at 1.010 s, when fault is done on 1.00 s. After fault clearance, it settles at 33°

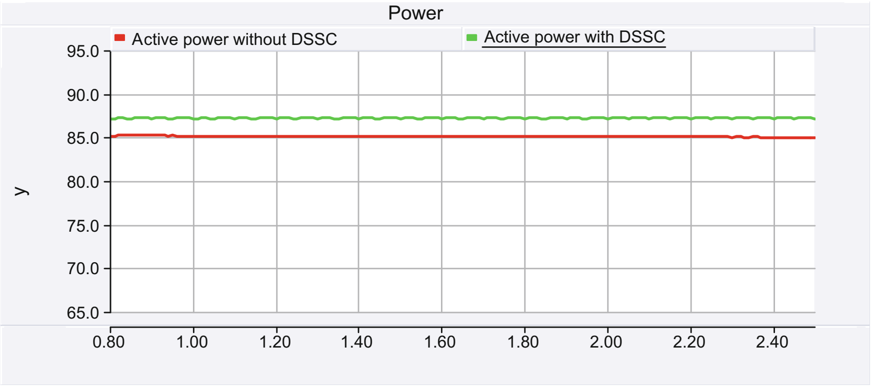

Fig. 6 Active power flows in line with and without DSSC

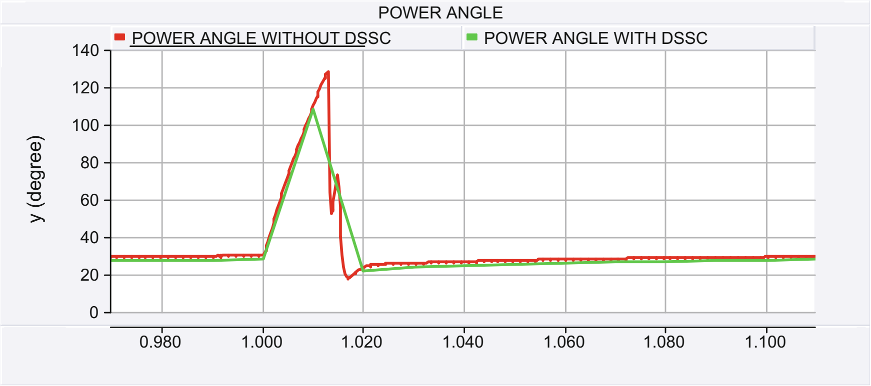

Fig. 7 Comparison of power angle of generator with DSSC and without DSSC

The above simulation has 09 number of DSSC connected in line which damped up to 16 degree. Hence, it is seen that the power oscillation damps faster with DSSC as compared to without DSSC.

5 Conclusion and Future

In order to penetrate large chunk of transmission and distribution system market, it is necessary to reduce cost and improve reliability of existing FACTS devices. DSSC is a member of D-FACTS family that improves power transfer capability and system stability. As of now, DSSCs are under development and few prototypes have been reported. More research is required to justify its commercial applicability.

References

1. Kundur P (1994) Power system stability and control. Prentice Hall NY, U.S.A
2. Divan D, Gohal H (Nov 2007) Distributed FACTS—a new concept for realizing grid power flow control. IEEE Trans 22:2253–2260
3. Fajri P, Afshamia S (2008) Modeling simulation and group control of distributed static series compensator. American engineering and applied science pp 347–357
4. Divan DM (Oct 2004) A distributed static series compensator system for realizing active power flow control on existing power flow control. Power Syst Conf Exposition, IEEE PES 2:654–661
5. Hingorani NG Understanding FACTS: concepts and technology of flexible AC transmission system. IEEE press 2000
6. Golshannavaz S, Mokhtari M, Khalilian M, Naazarpour D (May 2011) Transisent stability enhancement in power system with distributed static series compensator. Irani conference
7. Simfukwe D, Pal BC, Begovic M, Divan D (July 26–30 2009) Control of power system static stability using distributed static series compensator. Power and energy society general meeting, Calgary, AB, Canada
8. Divan DM Control of power system static stability using distributed static series compensator. IEEE power & energy society general meeting, PES '09
9. Gygui L, schaudar C Sen K (Jan 1997) Static synchronous series compensator: a solid state approach to series compensation of transmission line. IEEE Trans power Delivery 12 n1:406–407
10. Divan D, Johal H (Nov/Dec2007) Design Consideration of series connected distributed FACTS converters. Ind Appl Conf 43(6)
11. Afsharnia S (03/2008) A PSCAD/EMTDC model for distributed static series compensator (DSSC). 2008 second international conference on electrical engineering
12. Abhishek R, Sadda A, Nebhanani L, Maheshwari VM, Pareek VS Optimul allocation of distributed static series compensator in power system using biogeoraphy based optimization. 2012 IEEE 5th India